

Article

Digital Transformation and Structural Challenges in the Moroccan Construction Sector: A Qualitative Study of Construction Professionals' Perspectives on Building Information Modeling and Artificial Intelligence Adoption

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Abstract

The digital transformation of Morocco's construction sector requires new approaches to address increasing project complexity and evolving regulatory demands. This exploratory qualitative study investigates the integration of building information modeling (BIM) and artificial intelligence (AI) through eight semi-structured interviews with field engineers, design engineers, sector experts, and researchers. The interview data were analyzed using thematic analysis in NVivo, supported by systematic coding, lexical similarity analysis, and cross-matrix synthesis. The findings reveal that BIM implementation in Morocco remains predominantly at Level 1, despite unanimous recognition of its high perceived usefulness. This gap between perceived usefulness and actual adoption is primarily explained by economic, institutional, legal, and capacity-related barriers rather than technological limitations. Participants also reported successful BIM-based clash detection experiences, highlighting measurable returns on investment through reduced design conflicts, rework, and project coordination efforts. Furthermore, AI was consistently perceived as an augmentation technology that enhances professional expertise and decision-making rather than replacing human roles. Based on these findings, the study recommends establishing a national BIM mandate, developing a national BIM competence center, strengthening regulatory and legal frameworks, and promoting context-specific research and development to accelerate Morocco's digital transition while adapting BIM and AI implementation to local technical, institutional, and climatic conditions. Future research should validate these findings through pilot implementation projects.

Keywords: building information modeling (BIM); artificial intelligence (AI); AEC sector; Morocco; qualitative research; NVivo; technological maturity; adoption barriers; life cycle assessment (LCA)

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1. Introduction

The AEC sector in Morocco is at the brink of digital transformation. The use of building information modelling is now standardized for cooperative design [1,2]. The “hybridization” with artificial intelligence offers new opportunities at the level of topological optimization, predictive risk analysis, real-time management, with projects for the digitization of life cycles of buildings [3–5]. It is not enough to buy software, as the integration of

these disruptive technologies within firms is more complicated [6,7]. The sweeping restructuring of organizations entails risk-management problems that are particular to developing nations [6,8]. The international and emerging economy literature also emphasizes that BIM maturity being low constitutes a direct technical barrier to AI application on account of it requiring a structured/standardized database [2,7,9].

To investigate these interconnected dynamics, this qualitative study raises three fundamental research questions focused on the Moroccan construction context: What are the major structural pathologies (budget overruns, inter-trade conflicts, logistical delays) that impair overall productivity on national construction sites? To what extent does the joint adoption of BIM and AI offer a technological fit capable of resolving these dysfunctions, and what key performance indicators (KPIs) allow a scientific assessment of the return on investment? What sociological, economic, capacity-related, and legal barriers particularly regarding algorithmic liability impede the diffusion of these innovations in Morocco? An exploratory qualitative approach was implemented with a panel of targeted experts [10,11]. Data were collected through semi-structured interviews using a rigorous interview guide the full version of it can be found in Appendix A [10,12]. The entire empirical corpus was then subjected to systematic processing using NVivo software version 12 Plus, which is a qualitative data analysis software used to systematically code, organize, and analyze textual data, supporting thematic analysis within the analytical workflow, an approach recognized for its robustness in modelling technology adoption barriers in construction [13]. Following verbatim transcription and NVivo data preparation, a lexical similarity test was run on the corpus; its positive result validated the lexical and conceptual coherence of the discourses. Coding then generated the study's thematic nodes [13,14]. After validating data convergence, a condensation matrix was constructed. The results and discussion presented below are grounded directly in this NVivo qualitative matrix [14,15].

2. Literature Review

Building information modeling (BIM) is a collaborative methodology and information management framework that enables the creation, integration, and exchange of digital representations of a built asset throughout its lifecycle. Although its early adoption was often associated with three-dimensional digital modeling tools, BIM has evolved into a comprehensive scientific and methodological approach supporting multidisciplinary collaboration, data-driven decision-making, and lifecycle management in the architecture, engineering, and construction. However, the concept in its true form is a multi-dimensional digital representation allowing the management of information of the building during its complete life cycle. Geometric, technical, operational and project information is integrated in a shared data environment and model-building details are circulated among stakeholders [1,16]. Intelligent data handling and automation are fundamentally supported by the structured and standardized information contained within the BIM model, thus enabling the effective use of digital technologies. As set forth in ISO 19650, standardized information management practices are necessary to achieve consistency and interoperability [1,2]. The BIM environment is crucial for artificial intelligence (AI) to generate meaningful and reliable output through huge quantities of data. Artificial intelligence could utilize building information modeling (BIM) models to scan construction data for patterns and aid decision-making processes [4,17]. A combination of BIM and AI can automate various construction tasks like clash detection, schedule optimization, risk prediction, and resource allocation. Data produced through BIM could use machine learning and computer vision approaches to increase overall project performance. It will significantly reduce human involvement in repetitive work [4,17]. Enhanced digital twins combine BIM and AI. They create digital replicas of physical objects through enhanced ver-

sions of BIM models. Enhanced digital twins offer functionality for monitoring, description and prediction [3]. Multiple studies show that together BIM and AI lead to fewer delays, better cost control, improved resource management, and sustainability value during the construction phase [4,5,17]. These developments reflect the broader transition toward Construction 4.0, characterized by intelligent, data-driven, and interconnected construction ecosystems [6,18].

The AEC (architectural, engineering and construction) literature has known for a long time that Construction 4.0 technologies are largely responsible for productivity improvement, sustainability and innovation. For example, employing BIM, AI, digital twins, and substantial data assessment [4,6,17]. Digital technologies and platforms offer significant opportunities to enhance efficiency, collaboration, and innovation across industries. However, their implementation varies considerably across countries and regions due to differences in economic, technological, and institutional contexts. Emerging economies, in particular, often face structural challenges, including limited financial and technical resources, underdeveloped digital infrastructure, and regulatory uncertainty, which can hinder the adoption of these technologies [6,7]. In this context, theoretical frameworks provide a valuable basis for understanding the factors influencing technology adoption and the challenges associated with implementing new digital technologies. According to the technology acceptance model (TAM), users adopt an innovation due to perceived usefulness and perceived ease of use [19], while the unified theory of acceptance and use of technology (UTAUT) highlights the importance of performance expectancy, social influence, and facilitating conditions [20]. Institutional theory explains that regulatory requirements, professional norms, and outside pressure influence organizations' practices [21]. The construction industry has been changing rapidly in recent times. Industry innovators who develop powerful apps and CAD programs to create accurate drawings that minimize conflicts between contractors and designer are a key issue in the adoption of BIM. BIM and AI in the construction industry rely on tagged, information-rich digital components to create accurate three-dimensional representations of the physical elements of a building [7,21].

Current research demonstrates that there is a significant global interest in digital transformation in construction. In addition, fast growth can be seen in studies relating to BIM, AI, digital twins, big data, and other Construction 4.0 technologies [4,17,18]. In contrast to developed countries, there are not too many studies on developing economies which are weighted [6,17]. A preliminary bibliometric assessment reveals a significant disparity between global research output and studies focusing on the Moroccan context; this was achieved through a specific search query using a number of keywords related to the subject at hand in databases like Scopus, Web of Science and so on, while focusing and limiting the search to Morocco. In addition, more particular keywords such as BIM and AI integration do not yield many papers investigating these topics and applying them to the construction issues in Morocco. The existing literature provides little empirical evidence regarding the perceptions, experiences, and expectations of local construction professionals, leaving important contextual factors insufficiently explored. Consequently, an exploratory qualitative approach is particularly appropriate for investigating this emerging phenomenon. Qualitative research enables a deeper understanding of stakeholder perspectives, organizational practices, and contextual barriers that cannot be fully captured through quantitative methods alone [10,12,14]. Semi-structured interviews are especially suitable for exploring under-researched topics and generating rich insights from industry experts [10,12,15]. Therefore, this study seeks to address an important research gap by examining BIM–AI integration from the perspective of Moroccan construction professionals and contributing to both academic knowledge and practical digital transformation initiatives within the national construction sector [10,11]. Unlike previous studies

that primarily examine BIM or AI independently or focus on technological implementation, this research investigates their combined adoption from the perspective of Moroccan construction professionals. This study is trying to offer one of the first qualitative analyses to capture how stakeholders across the Moroccan AEC sector perceive the opportunities, barriers, and enabling conditions for integrating these digital technologies, thus generating practical recommendations for policy makers, industry practitioners, and academic institutions. This study, beyond technology adoption, also addresses two underexplored dimensions in the literature. It examines the emerging issue of algorithmic liability associated with AI-assisted decision-making in BIM environments and explores the potential of BIM and AI to support life-cycle assessment of vernacular materials adapted to Morocco's local climatic and construction context. These context-specific contributions extend current research on digital transformation in the AEC sector.

3. Methodology

3.1. Sampling Method and Empirical Data Collection

The validity of qualitative research depends on the relevance of its sampling and the rigor of field data collection. To capture an exhaustive and systemic view of the digital transition in Moroccan construction, this study used purposive sampling, targeting expert profiles with direct and diversified experience in the AEC ecosystem. The final panel includes eight interviewees that are from different backgrounds, i.e., field engineers, study engineers, academic researchers, and sector experts. A total of ten experts meeting the predefined selection criteria were invited to participate, of whom eight accepted and completed the interviews. Recruitment continued until thematic saturation was achieved, with no substantially new themes or insights emerging during the final interviews. The final sample was therefore considered sufficient to ensure representation of the principal stakeholder groups involved in BIM and AI adoption within the Moroccan AEC sector while providing adequate depth for qualitative analysis. Data collection was structured around semi-structured interviews using a guide organized around six distinct analytical themes. This approach offers the flexibility needed to explore subtle cultural barriers and informal organizational dynamics, while maintaining a strong conceptual anchor around BIM maturity assessment and the functional coupling of BIM and AI. Interview sessions, averaging 45 to 60 min, were fully recorded with explicit participant consent, guaranteeing complete anonymity.

3.2. Corpus Preparation and Lexical Similarity Analysis in NVivo

Empirical data processing began with full verbatim transcription of all audio recordings. The resulting textual documents underwent semantic cleaning and normalization before being ingested into NVivo for qualitative analysis. Before any thematic coding, the corpus was subjected to an algorithmic lexical similarity test within NVivo, calculated through Jaccard similarity coefficient, which was calculated across interview transcripts. A threshold of ≥ 0.40 was adopted as indicative of sufficient conceptual alignment within the corpus, in line with established NVivo-based qualitative studies [13]. The result was positive, evidencing significant conceptual alignment within the sample. This lexical similarity demonstrates that, despite the diversity of respondents' roles (strategic views in study offices vs. productivity imperatives on site), actors share a common semantic representation of the structural pathologies of the Moroccan AEC sector and of the opportunities linked to Construction 4.0 technologies.

3.3. Node Architecture and Theoretical Convergence Control

Once internal corpus coherence was validated, a deductive-inductive coding approach was deployed to structure the qualitative database. The category architecture materialized in NVivo through hierarchical main nodes and child nodes, initially mapped onto the interview guide's analytical objectives [15]. Textual segments were systematically assigned to corresponding nodes. During this indexing phase, rigorous convergence control was performed by cross-checking encodings by respondent profile. Saturation was operationalized by monitoring the emergence of new codes and themes after each successive interview. Following the coding of the sixth transcript, only minor refinements to existing codes were observed, and the seventh and eighth interviews yielded no additional themes or conceptual categories beyond those already identified. This stability of the coding framework across the final transcripts was used as the practical criterion for determining thematic saturation, consistent with established qualitative research guidance [11,15]. Verification of this thematic convergence confirms the attainment of theoretical saturation, the point at which analysis of additional transcripts no longer generates new properties or conceptual dimensions.

3.4. Matrix Condensation and Preparation for the Writing Phase

The final methodological step synthesized the encoded data volume by generating a data condensation matrix through NVivo's cross-matrix query function. This spatial conceptualization technique enables structured mapping of critical intersections between participant attributes (e.g., years of experience or project typology) and the occurrence of major themes or systemic barriers. By reducing massive verbatim extracts into interconnected, condensed idea configurations, this matrix extracts the essence of expert discourses without altering their contextual richness. The highly structured results from this qualitative matrix constitute the direct empirical and analytical foundation from which the following section is written.

4. Results

This section presents and interprets the empirical findings from NVivo thematic coding of eight semi-structured interviews with Moroccan AEC professionals. The analysis is organized around three interdependent axes: (4.1) structural pathologies of the Moroccan AEC sector; (4.2) BIM maturity and perceived technological adequacy; (4.3) a multi-dimensional mapping of barriers to digital adoption. Each subsection is accompanied by tables to objectify the spread and frequency of themes. Table 1 shows the sociodemographic and professional profiles of the eight participants.

Table 1. Sociodemographic and digital profile of participants (n = 8).

Code	Age	Sex	Training	Role	Sector	Digital Experience
Int 1	32	M	Civil Eng.	Project engineer	Public Buildings	7–8 yrs Modelling tools (limited BIM use)
Int 2	32	M	Civil Eng.	Site engineer	Industrial	4–5 yrs Standard tools, model reading
Int 3	28	F	Architect	Architect	Buildings	6 yrs Daily BIM (Revit, Navisworks, spatial AI)
Int 4	31	F	Civil Eng.	Project Director	Buildings	8 yrs AutoCAD, Revit (partial), MS Project
Int 5	36	F	Master's Degree and PhD	Consultant and GIS Engineer	Infrastructure/buildings	3 yrs BTP QGIS, ArcGIS, Revit, Python/AI
Int 6	38	M	Civil Eng. and PhD	CE Consultant	Buildings/infrastructure	10+ yrs ANSYS, Robot SA, FLAC 2D, Revit
Int 7	40	M	Civil Eng. and PhD	CE Consultant and R&D	Buildings/infrastructure	10 yrs ANSYS, Revit, Navisworks, Generative Design
Int 8	35	M	Civil Eng. and PhD	CE Consultant and R&D	Buildings/R&D	6 yrs Grasshopper, Galapagos, Revit, Python scripts

Note: The purposive sample covers four complementary profiles of field engineers (Int 1, 2, 4), an architect (Int 3), a GIS engineer (Int 5), and academic researchers/consultants (Int 6, 7, 8) ensuring intra-professional triangulation of perceptions.

4.1. Current Pathologies of the Moroccan AEC Sector

All participants converge on a shared diagnosis built around seven recurring structural pathologies. Table 2 shows the distribution of these pathologies across interviewees.

Table 2. Distribution of AEC sector pathologies by interviewee.

Pathology	Int 1	Int 2	Int 3	Int 4	Int 5	Int 6	Int 7	Int 8	Freq.
Communication fragmentation/silos	✓	✓	✓	✓	✓	✓	✓	✓	8/8
Schedule overruns (logistics/decisions)	✓	✓	✓	✓	✓	✓	✓	✓	8/8
Budget overruns	✓	✓	✓	✓	✓	✓	✓	✓	8/8
Variable execution quality	✓	✓	✓	–	✓	–	✓	✓	6/8
Supply chain failures (materials)	–	–	✓	–	✓	✓	✓	✓	5/8
Regulatory complexity RPS/RTCM	✓	✓	✓	✓	✓	✓	✓	✓	8/8
Undetected inter-trade conflicts	✓	✓	✓	✓	✓	✓	✓	✓	8/8
Lack of design-phase anticipation	✓	✓	✓	✓	–	–	–	–	4/8

Note: ✓ = pathology explicitly cited; – = not mentioned or not applicable to the interviewee's profile.

Table 2 reveals four unanimous pathologies (8/8): communication fragmentation, schedule overruns, budget overruns, and regulatory complexity. These constitute the bed-rock of the sectoral diagnosis.

4.1.1. Coordination Fragmentation and Information Silos

The most pervasive dysfunction, cited in all interviews, is the fragmentation of communication between project actors. This fragmentation generates cascading errors that only surface during the execution phase, when correction costs are disproportionate. Int 1 described it as “a coordination problem that affects everything downstream”, while Int 4 acknowledged “part of the problem comes from insufficient design-phase anticipation.” This observation aligns with the literature on information loss at handover in construction project management [22]. The absence of a common data environment (CDE) forces each discipline to operate from heterogeneous, version-divergent documents, which participants collectively call “siloeed working”.

“The sector suffers from severe fragmentation of communication between the various stakeholders, which leads to execution errors and costly rework.” (Int 3)

4.1.2. Schedule and Budget Overruns

Scheduling overruns and budget overruns were the conclusion of all. Three related causes exist: the first proximate cause is late procurement decisions, then comes supply chain fragility with non-compliant deliveries, and lastly subcontractor failures.

“Budget overruns are linked to variable-quality materials and imprecise paper-based estimates.” (Int 5)

Int 6 added that “just-in-time is not always mastered, and material traceability remains a challenge, especially in remote areas.”

4.1.3. Regulatory Complexity as Structural Pressure

Six participants refer to a complexity-related pathology of the second order. Specifically, RPS 2011 [23] and RTCM [24] impose multi-physics seismic and thermal calculations that are coupled and analysis of those cases are beyond the energy added to the materials of 2D-CAD. As such, this regulatory pressure is a latent yet substantial institutional driver of compliance, because any verification of compliance only becomes computationally feasible in a federated digital model. The isomorphic pressure from public regulatory agen-

cies could prove more decisive than purely market-driven incentives as a neo-institutionalist reading would suggest.

“The strict application of RPS 2011 and RTCM requires an unprecedented level of analytical precision. Methods based on 2D plans struggle to cross-reference thermal constraints with seismic design.” (Int 3)

“With the new RPS 2000/2011 and the evolution of architectural forms, traditional methods are no longer sufficient to integrate soil-structure interaction and second-order effects.” (Int 6)

4.2. BIM Maturity and Perceived Technological Adequacy

4.2.1. Definitional Convergence: BIM as a Collaborative Process

There is a commonality of definition across the full range of participants, regardless of their seniority or specialization. Digital building information modelling (BIM) does not use software tools but a process or method which leads to collaborative working between project participants and greater integration through the use of a common digital model. Because of this clarity, it is important to note the implications: the PU which is the central TAM construct cannot be contaminated by definitional ambiguity and what is a barrier to adoption is structural and institutional rather than cognitive.

“BIM is not just a simple 3D software tool: above all, it is a way of working together around a shared digital model. As ISO 19650 reminds us, this collaborative approach enables more reliable decision-making throughout the building’s lifecycle.” (Int 3)

“BIM cannot be reduced to the 3D model. It is a collaborative process based on a single digital model, integrating time (4D), cost (5D), and even maintenance. It is a project governance tool.” (Int 6)

4.2.2. Sectoral Maturity Level: BIM Level 1 Predominant

Despite this conceptual clarity, participants unanimously describe actual BIM deployment in Morocco as largely confined to Level 1 (isolated 3D modelling) [25,26]. Table 3 summarizes the maturity level estimated by each interviewee. From a UTAUT perspective, this maturity deficit is attributable less to low perceived utility which is high across the sample than to weak facilitating conditions (FC): prohibitive costs, absence of standards, and interoperability failures.

Table 3. Perceived BIM maturity level by interviewee.

Interviewee	BIM Level	Stage	Sector	Key Observation
Int 1	Level 1	Isolated 3D	Public buildings	BIM use limited; no collaboration; 2D plans dominant
Int 2	Level 1	Isolated 3D	Steel/industrial	Model reading only; 100% 2D execution
Int 3	Level 1–2	Transition	Tertiary Tangier	Federated model on major projects; clash detection performed
Int 4	Level 1	Isolated 3D	Multi-sector BTP	Hybrid phase; occasional use; no CDE
Int 5	Level 1–2	Transition	Infrastructure/GIS	ISO 19650 enforced on projects; Solibri, Revit tools used
Int 6	Level 1–2	Transition	Buildings/infra	Collaborative BIM on large projects; custom protocols developed
Int 7	Level 1	Isolated 3D	School/health buildings	BIM on pilot projects; local SMEs still outside BIM
Int 8	Level 1–2	Transition	R&D/teaching	Advanced mastery (generative); BIM required on contracts > MAD 50M

Table 3 shows that the majority of participants situate their professional context at Level 1, with four interviewees (Int 3, 5, 6, 8) signaling a transition toward Level 1–2 on specific projects. No participant described an operational Level 3 environment.

4.2.3. Proof of Efficacy: Clash Detection as a Reference Case

Five participants reported direct clash detection experiences constituting empirical evidence of technological value. Table 4 documents these cases comparatively. These testimonies align with the international literature reporting 15–40% reductions in RFIs and change orders on BIM projects [27].

Table 4. Documented BIM clash detection cases and measured economic impacts.

Source	Project	Conflict Detected	Corrective Action	Economic Impact
Int 3	Tertiary complex, Tangier	HVAC ducts crossing seismic shear walls	Detection and correction at design stage	Major cost overrun avoided + contract amendment (unquantified)
Int 4	Building project, Morocco	HVAC network vs. structure conflict	Clash detected pre-execution	Costly on-site rework avoided
Int 6	Underground car park	Transfer beam vs. central technical ducts	Beam repositioned at design stage	Three weeks rework avoided + significant cost saving
Int 7	Clinic, Agadir	Seismic shear walls vs. VMC ducts	Upstream correction at design stage	MAD 800,000 rework avoided ROI 350%
Int 8	Building project (expert review)	Cross-wall beam intersecting central technical duct	Resolved at design stage, near-zero cost	One month delay avoided + costly concrete rework prevented

“When a software tool instantly identifies 150 clashes during model federation, it exceeds human cognitive capabilities within a given timeframe. The tool provides raw data; it is the collaborative human organization that transforms it into operational intelligence.” (Int 6)

This epistemological distinction between algorithmic detection and human resolution mirrors the debate on AI augmentation versus automation in knowledge work [28].

4.3. Mapping Barriers to Digital Adoption

The condensation matrix shows that the NVivo node N3 “Technology adoption barriers” is the densest node where all eight participants are present. There were three types of barriers which appeared: economic, capacity related and legal/institutional. Table 5 presents the full mapping. The economic, capacity, legal, and cultural dimensions echo the barrier taxonomy established for MENA and other developing-economy AEC sectors [29].

Table 5. Multi-dimensional mapping of BIM/AI adoption barriers in the Moroccan AEC sector.

Category	Sub-Barrier	Description	Freq.	Sources
Economic	Access costs	Licenses, hardware, training prohibitive for SMEs	8/8	Int 1–8
Economic	Tender pressure	Lowest-bid culture squeezing digital margins	6/8	Int 2, 3, 4, 5, 6, 7
Economic	ROI not perceived	Lack of short-term economic demonstration	5/8	Int 1, 2, 3, 4, 6
Capacity	Academy/field gap	2D-CAD curricula; graduates used as 3D draughtsmen	8/8	Int 1–8
Capacity	Generational gap	Experienced technicians with no digital model skills	6/8	Int 4, 5, 6, 7, 8
Capacity	IFC interoperability	Data loss on IFC export; inconsistent naming conventions	7/8	Int 1, 3, 4, 5, 6, 7, 8
Capacity	No national BIM guide	Absence of national best-practice framework	7/8	Int 1,3,5,6,7,8
Legal	Regulatory void in public contracts	No BIM clause in tender specs; no mandatory threshold	8/8	Int 1–8
Legal	Algorithmic liability	DOC Art. 769 silent on algorithmic fault or BIM L3	7/8	Int 1,3,4,5,6,7,8
Legal	Intellectual property	Ownership of collaborative model undefined (Law 17–97)	5/8	Int 3,5,6,7,8
Cultural	Resistance to change	‘2D plans have always worked’ inertia + silo preference	7/8	Int 1,2,3,4,6,7,8
Cultural	Lack of transparency	Reluctance to share information between actors	4/8	Int 1,2,3,6

4.3.1. Economic Barriers: Cost Structure and Market Dynamics

The eight-member group all cited licensing costs, hardware investments, and training needs as the key disincentive of an economic nature.

“Between overpriced licenses, expensive hardware, and tenders always won by the lowest bidder, small Moroccan firms simply cannot get started.” (Int 3)

Int 7 provided an example on ROI in the sample (350% on a clinic project), illustrating that the business case exists but is insufficiently documented at sector level to shift investment norms.

4.3.2. Capacity Barriers: Skills Gap and Interoperability Failures

Mismatch between what is taught in academic courses and actual requirement was stated by all. Senior site engineers are wise and have good constructability judgment, but they sometimes end up never opening any BIM software. This creates some inter-generational tensions.

“Our training programs produce excellent engineers, but the field workforce often lacks basic digital skills. Massive upskilling is essential.” (Int 5)

Issues of IFC interoperability constitute a particular second barrier to capability. According to Int 3, “after every exchange of IFC, I have to spend hours cleaning and re-parameterizing models.” Likewise, Int 5 is mandating ISO 19650 compliance because there is no national BIM protocol.

4.3.3. Legal and Institutional Barriers: The Regulatory Void

The most structurally determinant barrier category is legal and institutional. The absence of a BIM mandate in public procurement was noted by all participants.

“Most of the time, it is not imposed by the project owner. It is often an internal initiative or linked to specific projects.” (Int 4)

Beyond this procurement deficit, participants identified a deeper legal void regarding algorithmic liability. The Dahir des Obligations et Contrats (DOC), in its Article 769 on decennial liability, is structurally inadequate for BIM Level 3 environments or AI-generated errors. This finding joins international debates on AI governance in construction.

“In a level 3 BIM model modified simultaneously by several actors, or when faced with a calculation error generated by AI, current legislation is silent on the allocation of fault, creating a major legal void.” (Int 3)

“In practice, it remains the engineer or the design office that signs off on the plans who is liable, even if they used an AI tool. There is no clear case law.” (Int 6)

4.3.4. Performance Measurement: Key Performance Indicators

Participants provided precise indicators to objectify BIM/AI gains. Table 6 summarizes these KPIs by impact dimension.

Table 6. Key Performance Indicators (KPIs) for BIM/AI impact measurement synthesis of responses.

Dimension	Indicator (KPI)	Target/Threshold	Field Illustration
Rework reduction	Upstream conflict detection rate	≥30% (Int 6)/<5% of structural items	Int 6: BIM zone vs. traditional → 70% fewer interferences
Direct savings	ROI = (costs avoided – impl. cost)/impl. cost	ROI 350% on clinic project (Int 7)	Agadir clinic: MAD 800,000 saved
Material optimization	Reduction in steel/concrete offcuts	Waste <20% (Int 5)	Parametric reinforcement: solution in 2 days vs. 2 weeks (Int 8)
Schedule adherence	Actual vs. planned schedule variance	Schedule compliance ≥90% (Int 5)	Reduced coordination time (Int 8)
Coordination	Reduction in RFIs and change orders	No. of meetings before/after model	Data reuse rate/zero re-entry (Int 8)
Site safety	PPE incidents detected by AI vision	Monitoring precision ≥95% (Int 5)	Cameras/drones: real-time PPE non-compliance (Int 6)

4.3.5. Policy Recommendations: A Three-Pillar Architecture

Participant recommendations converge on a coherent three-pillar policy architecture. Table 7 presents this mapping. Their convergence addresses simultaneously coercive, normative, and mimetic isomorphic mechanisms, strengthening the transferability of these prescriptions.

Table 7. Convergent policy recommendations mapping by pillar and source.

Pillar	Measure	Description	Sources/Models
Pillar 1	Regulatory mandate	Mandatory BIM Level 2 on public contracts > MAD 50M with IFC delivery clauses in tender specs	Int 5, 6, 7, 8 Model: UK BIM L2 Mandate 2011 [30], Plan BIM 2022 (FR)
Pillar 1	Procurement code reform	Integration of a standard BIM clause + progressive thresholds in the public procurement code	Int 7, 8
Pillar 2	National BIM competence center	BIM Morocco hub: certification, national guide, standardized IFC naming conventions	Int 5, 6, 7, 8 Model: BIM Task Group UK, PTNB France
Pillar 2	Short certified training programs	Open to working professionals; funded by a sectoral fund	Int 5, 6, 7, 8
Pillar 2	“BIM Project” label	Tax benefit or tender advantage for certified BIM projects	Int 7
Pillar 3	BIM/AI R&D–Moroccan context	BIM databases for vernacular materials (tadelakt, pisé, alfa); seismic profiles Rif/AI Hoceima; arid climate	Int 3, 5, 6, 7, 8
Pillar 3	AI-BIM industrial chairs	Lab–industry partnerships for measured pilot deployments	Int 6, 8
Pillar 3	Localized seismic AI models	ML models calibrated on Moroccan signals (not solely Californian/Japanese)	Int 6, 7

5. Discussion and Strategic Perspectives

Section 4 delivered the empirical results from the eight interviews and NVivo coding. This section provides a transversal, interpretive reading of these data: crossing thematic nodes to extract structuring convergences and tensions (Section 5.1), anchoring them in theoretical frameworks (Section 5.2), formulating operational recommendations for public authorities (Section 5.3), and opening onto the specific strategic opportunity of integrating life-cycle assessment of local materials into Moroccan BIM models (Section 5.4).

5.1. Interpreting the Convergences Identified by NVivo

NVivo processing of the condensation matrix produced eight thematic nodes whose saturation and co-occurrence allow a robust sectoral diagnosis. Table 8 synthesizes the density and intensity of each node and the degree of inter-interviewee consensus.

Table 8. NVivo node synthesis: frequency, intensity, and degree of consensus.

NVivo Node	Freq.	Intensity	Consensus	Synthetic Content
N1–Context and profile	8/8	Very high	Unanimous	Diverse profiles: field engineers, architect, GIS, academics. Multi-professional legitimacy.
N2–Site pathologies	8/8	Very high	Unanimous	Seven cross-cutting pathologies: fragmentation, delays, costs, RPS/RTCM, quality, materials, silos.
N3–Adoption barriers	8/8	Very high	Unanimous	Twelve sub-barriers: economic, capacity, legal, cultural. Densest node in the matrix.
N4–BIM/AI definitions	8/8	High	Unanimous	Convergence: BIM = collaborative process (not software). AI = decision-support tool. Spontaneous ISO 19650 reference (3/8) [2].
N5–Concrete uses	6/8	High	Partial	Clash detection universally cited. Field AI (drones, vision) known but rarely deployed. Parametric scripts (Int 6, 8).
N6–Validation and ROI	5/8	Moderate	Partial	Five documented clash detection cases. One quantified ROI: 350% (Int 7). Convergent KPIs.
N7–Adoption steering	7/8	High	Unanimous	Absence of public mandate = top institutional barrier. Voluntary vs. regulatory transition.
N8/N9–Foresight and R&D	8/8	Very high	Unanimous	Three recommended pillars: public mandate, competence center, local R&D (materials, seismic, arid climate).

Note: Freq. = number of interviewees contributing to the node out of 8. Intensity assessed on the richness and depth of coded extracts.

5.1.1. Primary Convergence: The Diagnosis Is Unanimous

Table 8 reveals a consensus that is rare in qualitative research: six of the eight nodes obtain a frequency of 7/8 or 8/8 with “high” or “very high” intensity [15]. This thematic saturation reached as early as the sixth interview for nodes N2, N3, and N4 validates the robustness of the corpus despite its modest size, in line with established standards. The convergence crosses cleavages that could have generated divergent views: public/private (Int 1 vs. Int 3), academic/field (Int 7–8 vs. Int 2–4), engineering/architecture (Int 1–2 vs. Int 3). The absence of divergence on fundamentals suggests a latent sectoral consensus not yet translated into public policy [31].

5.1.2. Secondary Convergence: AI Perceived as Augmentation, Not Substitution

AI as a tool for augmenting human capabilities, not as a substitution agent, is what all participants (8/8) converged towards. This is consistent with the theoretical framework of Raisch & Krakowski (2021) [28], but presents a Morocco-specific nuance: due to being aware of the limits of local data on which an acute resistance to substitution is anchored.

“The tool provides raw data; it is the collaborative human organization that transforms it into operational intelligence.” (Int 6)

“The engineer will remain indispensable for validating assumptions, integrating local construction constraints that are not always present in databases, and ensuring final responsibility.” (Int 8)

5.1.3. Structuring Tensions Identified by Triangulation

Beyond convergences, NVivo node triangulation reveals six paradoxical tensions structuring the adoption dynamic. Table 9 maps these with their observed consequences and corresponding resolution paths.

Table 9. Structuring tensions and paradoxes from NVivo node triangulation.

Tension/Paradox	Description	Observed Consequence	Resolution Path
High perceived utility vs. very low adoption	High PU (8/8), low PEOU (structural barriers)	Classic TAM paradox: conviction without action [19]	Address FC (costs, legal framework) rather than further persuasion
Academic BIM training vs. digital desert in the field	BIM-trained graduates vs. unprepared companies (Int 8)	Wasted human capital; generational frustration	Continuous professional certification + inter-generational mentoring
Demonstrated ROI (350%) vs. lack of investment	Economic proof exists but remains confidential	Information asymmetry blocking decision-makers	National BIM ROI observatory (public database)
Strict regulation (RPS/RTCM) vs. no mandatory BIM	Standards requiring coupled calculations impossible in 2D (8/8)	Institutional contradiction: law makes BIM necessary without imposing it	Regulatory alignment: mandate BIM as RPS compliance tool
Algorithmic liability void vs. growing AI use	DOC Art. 769 inadequate (7/8 participants)	Latent legal risk deterring early adopters	Targeted legislative revision: AI/BIM clause in DOC and Law 17–97
Abundant local materials vs. no BIM databases	Tadelakt, pisé, alfa, tafsa not parameterized (Int 3, 5, 6, 7, 8)	Innovation blocked for lack of certified data	National program for vernacular material characterization and modelling

The most striking paradox of high perceived utility versus near-zero adoption corresponds to a situation in which barriers are entirely exogenous to the actor: not a deficit of conviction, but a deficit of facilitating conditions. There is immediately a policy implication: awareness goals and technology demonstration campaigns are necessary but not the major, that is, most effective, lever. The transformation of the regulatory, financial, and normative institutional framework is a decisive lever. The most damaging institutional contradiction is that the State imposes, in its RPS 2011 and RTCM, multi-physics calculations that are impossible to perform in 2D, while not imposing the instrument making it possible (BIM) in its projects.

5.2. Theoretical Grounding: Four Interpretive Frameworks

The empirical results lend themselves to interpretation through four complementary theoretical frameworks whose articulation produces an integrated reading of the adoption phenomenon. Table 10 synthesizes this positioning.

Table 10. Synthetic theoretical positioning: frameworks × results × implications.

Theoretical Framework	Corresponding Results	Interpretive Contribution	Practical Implication
TAM/UTAUT (Davis 1989 [19]; Venkatesh 2003 [20])	High PU (8/8) Low PEOU (structural barriers) FC near-absent	Confirms: the barrier is not cognitive but structural and institutional	Address FC (costs, standards, legal framework) before investing in awareness campaigns
Institutional Theory (DiMaggio & Powell, 1983 [21])	Coercive pressure absent (no mandate). Normative pressure weak (no national guide) Mimetic pressure limited (few reference cases)	Explains the persistence of the blockage despite recognized utility	Simultaneously activate the three isomorphic mechanisms via the three-pillar action plan
Barriers to Adoption (Ndwandwe et al. (2024) [32])	Twelve sub-barriers mapped (economic, capacity, legal, cultural)	Confirms that BIM adoption barriers are multidimensional and mutually reinforcing across organizational, technical, economic, and institutional domains.	A systemic strategy addressing policy, organizational capabilities, technical capacity, and financial constraints is required rather than isolated interventions.
Augmentation vs. Automation (Raisch & Krakowski, 2021 [28])	AI perceived as assistant (8/8) No replacement feared in short term explicit tech vs. human distinction (Int 6)	Moroccan AEC sector rejects the automation paradigm in favor of augmentation	Train for AI as an augmentation tool (generative design, clash detection), not substitution

A cross-reading of Table 10 yields a central theoretical argument: the blockage of BIM/AI adoption in Morocco is not mono-causal. It results from the conjunction of a facilitating conditions deficit (TAM/UTAUT), a simultaneous absence of the three institutional isomorphic mechanisms (DiMaggio & Powell), an accumulation of interdependent multi-level barriers, and a default positioning on the augmentation paradigm due to insufficient local data (Raisch & Krakowski). Only a systemic response can produce durable transformation.

5.3. Recommendations for Public Authorities: Strategic Action Plan

Table 11 presents the operational action plan in three-time horizons, translating participants' prescriptions into concrete measures with institutional leads and reference resources.

Table 11. Strategic action plan for public authorities 0 to 10-year horizon.

Horizon	Action	Description	Lead	Resource/Model	Sources
Short term (0–2 yrs)	BIM mandate in public contracts	Implementation decree BIM Level 2 for contracts > MAD 50M; IFC clauses in tender specs	MHUA/E/DEPP	Regulatory budget	Int 5, 7, 8
Short term (0–2 yrs)	DOC legislative revision	Amendment Art. 769 + Law 17–97: algorithmic liability and model ownership	Ministry of Justice	–	Int 3, 6
Short term (0–2 yrs)	SME training subsidies	Sectoral fund (FNBTP/CGEM) for short BIM/AI certified training programs	OFPPT/FNBTP	50–100M MAD/yr	Int 4, 5, 8
Medium term (2–5 yrs)	National BIM Morocco Centre	Certifying hub: BIM Morocco guide, national IFC convention, trainer training	Government + FNBTP	Model: Plan BIM 2022 FR	Int 5, 6, 7, 8
Medium term (2–5 yrs)	“BIM Project” label	Tax benefit or tender advantage for certified BIM projects	MHUA/E/DGI	–	Int 7
Medium term (2–5 yrs)	BIM ROI Observatory	Public database of documented cases (costs avoided, timelines, ROI)	Universities + BET	Partnership research	Int 6, 7, 8
Long term (5–10 yrs)	AI–BIM industrial chairs	Lab–industry partnerships on local materials and seismic AI	EMI, ENSA, ...	PPP R&D	Int 6, 8
Long term (5–10 yrs)	Vernacular materials program	BIM database: tadelakt, pisé, alfa, tafsa, Anti-Atlas aggregates	CNRST/Universities	National R&D fund	Int 3, 5, 6, 7, 8
Long term (5–10 yrs)	Local seismic AI models	Calibration on Rif/Al Hoceima signals (vs. Californian/Japanese signals)	CNRST/CGS	International co-operation	Int 6, 7

Note: MHUA/E = Ministry of Housing, Urban Planning and Territorial Development; DEPP = Directorate of Studies, Planning and Prospects; FNBTP = National Federation of Building and Public Works; OFPPT = Office for Vocational Training and Work Promotion; CNRST = National Center for Scientific and Technical Research; CGS = Seismic Engineering Center; PPP = Public–Private Partnership.

5.3.1. Short Term (0–2 Years): Laying Regulatory and Financial Foundations

The first step must activate the coercive isomorphic mechanism by means of a BIM Level 2 mandatory decree for public contracts above MAD 50 million a threshold three participants spontaneously converged on. The initiative, motivated by the 2011 UK BIM Level 2 Mandate and the Plan BIM 2022 in France, generates an instant solvent demand that makes the investment in training and equipment economically rational. A focused revision of the DOC (Art. 769) and Law 17–97 through a BIM–AI standard clause in the design contracts would allow the early adopters to reduce legal uncertainties in parallel.

“The State, as the country’s primary project owner, should contractually mandate the use of BIM for all public infrastructure and building contracts exceeding a certain budget threshold.” (Int 3)

5.3.2. Medium Term (2–5 Years): Building the Competence Ecosystem

The creation of a national BIM competence center modelled on the UK BIM Task Group or France’s PTNB is the structural measure of this second horizon. Its four missions: produce a BIM Morocco Guide with standardized IFC naming conventions; certify continuing professional development programs; publish an annual BIM ROI observatory; and develop an open-source parametric BIM object library for Moroccan vernacular materials.

“We need a national BIM competency center: training, certification, guidelines. Without public impetus, we risk falling further behind.” (Int 6)

5.3.3. Long Term (5–10 Years): Anchoring R&D in the Moroccan Context

The third pillar is purely scientific. With two dominant axes: material characterization (developed in Section 5.4) and AI models calibrated to Moroccan-specific parameters and conditions.

“We need to train AI models on real seismic data from Moroccan territory. Our seismic zones (Rif, Al Hoceima) require locally calibrated models, not just on Californian or Japanese signals.” (Int 6)

5.4. Strategic Opportunity: Life Cycle Assessment of Local Materials via AI

One of the many opportunities identified in the interviews is the integration of life-cycle assessment (LCA) of local materials into Moroccan BIM models which constitutes the most strategically differentiating perspective. It is supported by five interviewees (Int 3, 5, 6, 7, 8) who converged on it. This section constitutes the second primary novel contribution of the study. While the legal liability analysis (Section 4.3.3) addresses a Moroccan civil law specificity, the AI–LCA–vernacular materials pathway addresses a gap in the international BIM–LCA literature, where databases are almost exclusively built on standardized industrial materials from North American and European markets.

5.4.1. The Diagnosis: An Unparameterized Material Heritage

Morocco possesses a wealth of vernacular construction materials tadelakt, pisé, alfa fibers, tafsa, Anti-Atlas and Middle Atlas stones, marine aggregates whose thermal, mechanical, and environmental properties are only partially characterized and virtually absent from BIM object libraries. These materials offer a double advantage: their carbon footprint is intrinsically lower than imported industrial materials, and their adaptation to the Moroccan climate is empirically proven by centuries of construction practice. Table 12 maps priority materials, properties to model, and recommended AI techniques.

“We need to create libraries of parametric BIM objects for Moroccan vernacular materials (tadelakt, rammed earth, local bricks) with their true thermodynamic and mechanical properties.” (Int 3)

“AI can predict the durability of local materials using accelerated test data, with accuracy far superior to current empirical models.” (Int 6)

Table 12. Mapping of AI × local Moroccan material opportunities for BIM-LCA.

Local Material	Key Properties to Model	Current BIM Status	Recommended AI Technique	Research Opportunity
Tadelakt (lime plaster)	Waterproof resistance, thermal conductivity λ	Not BIM-certified	ML on accelerated ageing tests	Durability prediction by climate zone: coastal, arid, mountainous
Pisé/rammed earth	Thermal inertia, compressive strength	Not BIM-certified	Coupled hygro-thermal simulation	RTCM optimization: thick low-energy walls, summer comfort
Alfa fibers (Stipa tenacissima)	Elastic modulus, bonding, durability	Not BIM-certified	Neural networks on mechanical test data	Fiber-reinforced concrete: partial steel substitution
Tafsa (dune sand)	Grain size, shape, impurities	Partial local reference	ML formulation optimization	Low-carbon concrete adapted to the Saharan zone
Anti-Atlas/Middle Atlas stone	Mechanical and thermal properties	Not BIM-certified	Multi-objective AI (strength + LCA)	Façades and structures: heritage + seismic performance
Marine aggregates concrete (Agadir)	Corrosion behavior, durability	Partial tests	ML marine durability prediction	Coastal structures: ports, breakwaters, coastal urbanization

5.4.2. The AI-LCA-BIM Approach: Methodological Architecture

The integration of AI into the LCA of Moroccan local materials can be structured in three complementary methodological layers:

Layer 1 ML characterization: neural networks trained on accelerated laboratory test data (hygro-thermal ageing, seismic cycling, UV exposure) to predict degradation curves for local materials without multiplying costly tests.

Layer 2 Multi-objective optimization: coupling environmental impact databases (carbon, water, waste) with evolutionary optimization algorithms (genetic algorithms, Galapagos in Grasshopper) to identify the most sustainable material–process combinations while meeting RTCM and RPS constraints.

Layer 3 BIM-5D–LCA integration: enriching the digital model with an LCA dimension (“BIM 6D”) by associating each BIM object with an environmental and health data sheet (EHDS) adapted to local materials enabling real-time carbon footprint evaluation during design, in line with Morocco’s Low-Carbon Strategy (PNLRCC).

“We can couple environmental impact databases with multi-objective optimization algorithms to select the most frugal material–process combination a real boost for meeting RTCM requirements.” (Int 8)

5.4.3. Potential International Scientific Contribution

BIM-LCA literature is almost exclusively built on standardized industrial materials from North American and European markets. Introducing vernacular desert or Mediterranean materials into this corpus would constitute a first-rank theoretical and empirical contribution to Scopus/WoS journals (Automation in Construction, Journal of Cleaner Production, Building and Environment). The coupling of LCA × seismic resistance integrating both environmental performance and structural durability under seismic loading is an emerging research axis not yet developed for the Mediterranean and North African context.

“I would like to combine seismic analysis and life cycle analysis, so that the green building is also a resilient building.” (Int 6)

5.5. Study Limitations and Research Perspectives

This study has several methodological limitations. First, the sample size ($n = 8$), while consistent with qualitative saturation standards [33], does not allow statistical generalization; the technophile, relatively young profile of participants may overestimate BIM/AI awareness relative to the sector average. Second, the study captured perceptions at a specific point in time, in a post-AI Haouz earthquake (2023) regulatory context. Third, the absence of longitudinal quantitative data on Moroccan BIM projects limits the establishment of causal relationships between BIM adoption and performance gains. Fourth, the ROI objective of the second research question is only partially met: a single unaudited respondent estimate cannot constitute scientific ROI assessment. These limitations open four future research avenues: a national quantitative survey on BIM adoption barriers; longitudinal case studies on BIM pilot projects with measured KPIs; action research on a vernacular materials BIM library; and a regional comparative study across Maghreb and sub-Saharan Africa on BIM deployment in emerging economies.

6. Conclusions

This study set out to investigate, through NVivo-structured qualitative analysis of eight expert interviews, how Moroccan AEC professionals perceive the integration of BIM and AI, what impedes their adoption, and what policy responses are indicated. Three principal findings emerge.

The first finding is empirical and confirmatory. The study documents, with a degree of cross-professional unanimity unusual in qualitative research, seven structural pathologies of the Moroccan construction sector: coordination fragmentation, schedule and budget overruns [34], variable execution quality, supply chain fragility, seismic and thermal regulatory complexity, undetected inter-trade conflicts, and insufficient design-phase anticipation. This diagnostic aligns with prior Moroccan literature [25,26,31,35,36], and the NVivo matrix analysis adds a structured co-occurrence mapping that reveals how these pathologies reinforce one another systemically. The five documented clash detection cases provide the first locally grounded evidence base linking BIM adoption to performance gains, though the figures reported are respondent claims rather than audited outcomes.

The second finding is analytical and counter-intuitive: the blockage of BIM/AI adoption in Morocco is not a cognitive problem. Perceived usefulness is high across the entire sample. The barrier is structural: a near-total absence of facilitating conditions (cost, standards, mandate, legal framework) and the simultaneous failure of all three institutional isomorphic mechanisms. This has a direct policy implication: awareness campaigns are insufficient without prior institutional transformation. The gap between strict regulatory requirements (RPS 2011, RTCM) and the absence of a BIM mandate constitutes the most acute institutional contradiction identified.

The third finding is normative and, in two respects, genuinely novel. First, the legal void around algorithmic liability in the Moroccan DOC specifically the inadequacy of Article 769 for BIM Level 3 and AI-generated error scenarios is a context-specific gap not previously foregrounded in either Moroccan or international BIM-AI literature. Second, the AI-LCA pathway for vernacular materials (tadelakt, pisé, alfa fibers, and tafsa) proposed by five participants represents a concrete research agenda that could position Moroccan research as a contributor to, rather than consumer of, the international BIM-LCA literature. Both contributions are more robustly grounded in participant testimony than the general barrier inventory, and constitute the study's strongest claim to originality.

Taken together, the three policy pillars recommended by the participants: a regulatory mandate, national competence center, and contextualized R&D address simultaneously the coercive, normative, and mimetic dimensions of the institutional deficit. Their cross-professional convergence suggests that the conditions for a coordinated national BIM strategy exist at the practitioner level. Whether public authorities will translate this consensus into policy remains the open question that the study cannot answer but clearly frames.

The principal limitations of this study sample size, technophile profile, single-country scope, and the absence of longitudinal performance data bound the generality of these conclusions. A national quantitative survey, longitudinal BIM pilot case studies, and cross-MENA comparative research constitute the logical next steps for a research program that this study can only begin to address.

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Institutional Review Board Statement: The study is based on qualitative interviews conducted in Morocco. Under the applicable Moroccan regulatory framework, researchers are not required to obtain prior approval or a declaration for this type of academic research. Before each interview, all participants were informed that their participation was voluntary and that the interviews were being conducted solely for academic and research purposes. Participants were also informed that anonymized excerpts from their responses might be published as part of the research findings. Furthermore, they were assured that all collected data would be treated confidentially, protected, and anonymized. No personally identifiable information is reported in the manuscript. The identities of the participants, or any other information that could reasonably identify them, have been omitted to preserve their privacy and confidentiality.

Informed Consent Statement: Informed consent was obtained verbally from all participants prior to the interviews. Participants were informed of the purpose of the study, the intended academic use of the collected data, and the measures taken to ensure confidentiality and anonymity.

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Abbreviations

The following abbreviations are used in this manuscript:

BIM	Building information modeling
AI	Artificial intelligence
AEC	Architecture, engineering, construction
CGS	Seismic Engineering Center
CNRST	National Center for Scientific and Technical Research
DEPP	Directorate of Studies, Planning and Prospects
FNBTP	National Federation of Building and Public Works
MHUA	Ministry of Housing, Urban Planning and Territorial Development
OFPT	Office for Vocational Training and Work Promotion
PPP	Public–private partnership
TAM	Technology acceptance model
UTAUT	Unified theory of acceptance and use of technology

CTAM	Construction technology adoption model
MENA	Middle East and North Africa
GIS	Geographic information system
LCA	Life-cycle assessment
LM	Lean management
R&D	Research and Development
RPS	Moroccan Seismic Regulation (Règlement Parasismique Marocain)
RTCM	Moroccan Thermal Construction Regulation (Règlement Thermique de Construction au Maroc)
WoS	Web of Science

Appendix A

The Interview Guide

Theme 1: Background and Context

1. Could you briefly describe your academic background and your current role within your organization?
2. How many years have you been practicing in the construction sector in Morocco, and what is your familiarity with digital construction tools?
3. In which type of projects are you primarily involved (infrastructure, buildings, industrial complexes)?

Theme 2: Current State, Structural Challenges, and Value-Added Assessment

1. “Beyond technology, if you were to diagnose the current state of the construction sector in Morocco, what are the three major problems or “pathologies” that hinder productivity on your sites (e.g., frequent budget overruns, clashes between trades, logistical delays, material quality)?”
2. “Are there specific challenges related to the increasing complexity of architectural projects or new regulatory requirements (seismic, thermal) that traditional methods now struggle to manage?”
3. “Among the challenges you just mentioned, which ones do you believe can be directly solved or mitigated by the implementation of BIM or AI? Do you have a concrete example where the use of a digital model prevented a costly error that would have gone unnoticed with traditional methods?”
4. “Do you think AI plays a role specifically in the design phase (topology optimization, calculations) or more in the execution phase (inventory management, safety, real-time monitoring) to address Moroccan constraints?”
5. “This is a crucial point for research: how do you measure the success of a BIM/AI implementation? What key performance indicators (KPIs) do you use to evaluate return on investment (ROI)? (e.g., reduction in rework rates, decrease in material waste percentage, adherence to schedule).”
6. “How do you distinguish between an improvement due to better human organization and an improvement directly attributable to the technological tool? In other words, how do you validate that it was indeed the algorithm or the model that provided the solution?”

Theme 3: BIM Maturity in Morocco

1. How do you assess the current level of BIM maturity in Morocco? Do you consider it to be isolated usage (simple 3D modeling) or collaborative (Level 2 or 3)?
2. In your recent projects, is BIM mandated by the client/owner, or is it an internal initiative to optimize your processes?
3. Do you encounter issues with interoperability or data standardization (IFC, naming conventions) with your local partners?

Theme 4: AI Integration and Perception

1. What is your operational definition of AI in the AEC industry? (e.g., automation, generative design, machine learning for prediction).
2. Do you use, or are you aware of, tools integrating AI for predictive analysis, clash detection, or material optimization?
3. Do you believe that generative design could replace certain current design tasks in Morocco?
4. Do you see potential for AI in construction site safety management or progress monitoring via image analysis (computer vision)?
5. How can AI improve life-cycle assessment (LCA) and the sustainability of local construction materials?

Theme 5: Barriers and Moroccan Context

1. In your opinion, what are the main barriers to the adoption of the AI-BIM pairing in Morocco? (Cost, training, legislative framework, corporate culture).
2. Is the current workforce sufficiently qualified to manage these new technologies? Is there a gap between academic training and actual field needs?
3. How does the current Moroccan legal framework handle intellectual property and liability in the event of an error committed by an algorithm or a BIM model?

Theme 6: Future Outlook and Strategy

1. If you had one recommendation for the Moroccan public authorities to accelerate this digital transition, what would it be?
2. How do you envision the typical Moroccan construction site in 10 years?
3. What should be the research priorities in order to adapt these global technologies to local constraints (local materials, climate, construction practices)?

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